Analyzing Aerosol - Cloud Interactions Using MODIS Data

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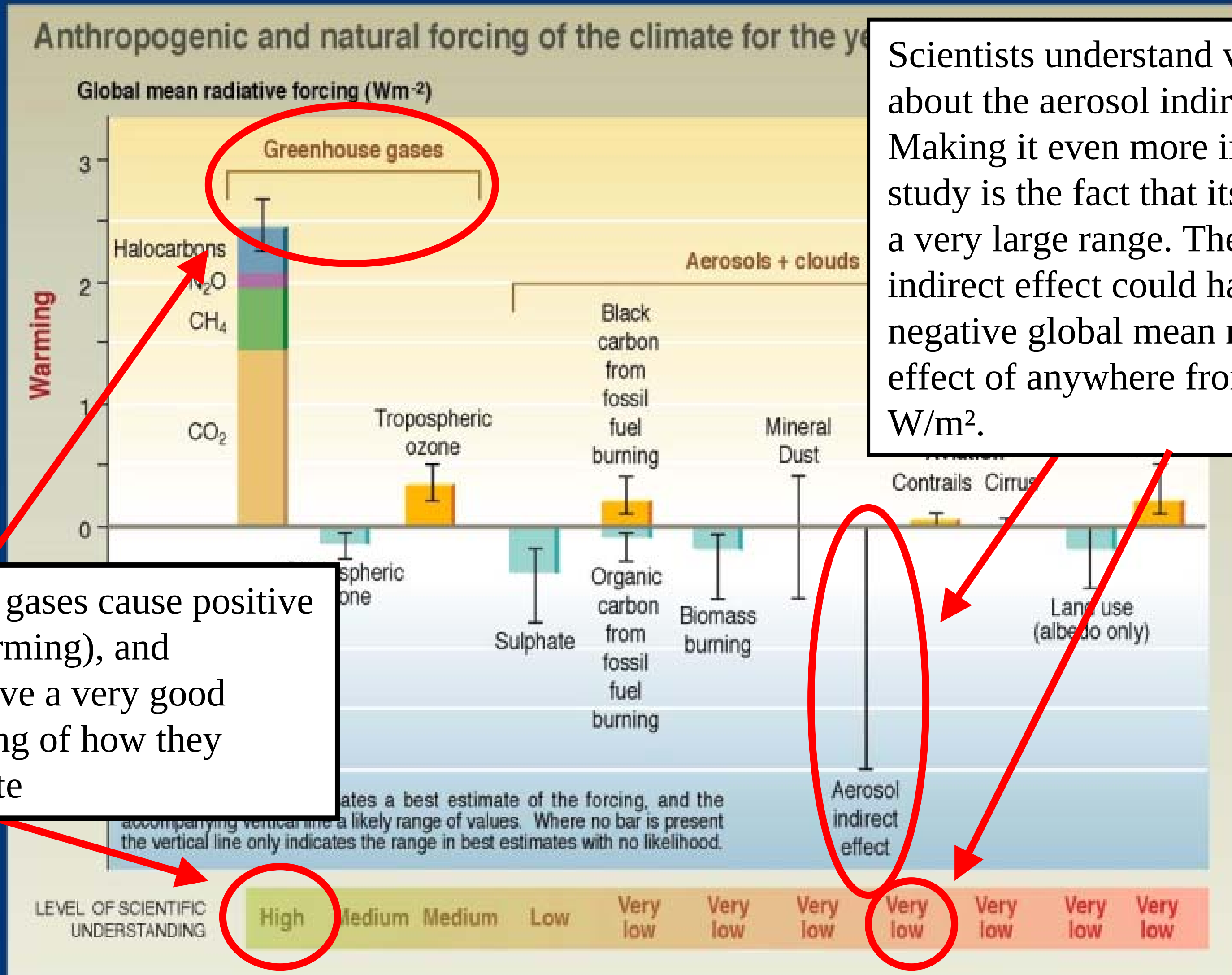
Atmospheric Forcing

- In order to understand how the Earth’s climate is changing, it is critical to make sense of each mechanism that causes warming or cooling in the atmosphere.
- Each process that changes the balance of radiation coming into and going out of the Earth-atmosphere system is known as atmospheric forcing.



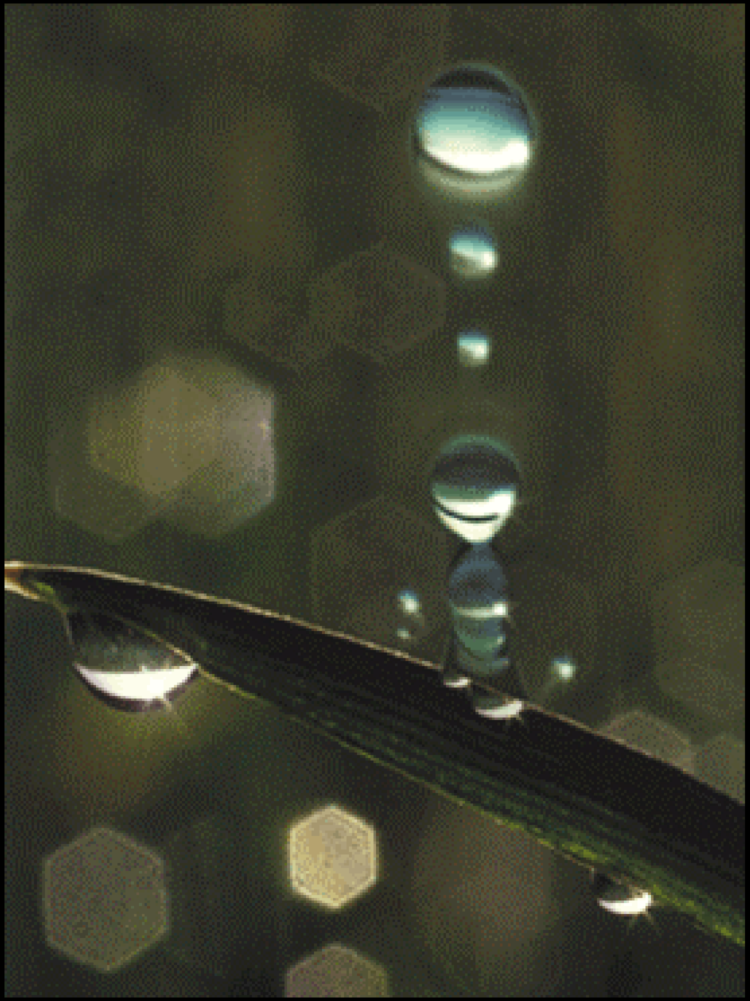
Scientists understand very little about the aerosol indirect effect. Making it even more important to study is the fact that its impact has a very large range. The aerosol indirect effect could have a negative global mean radiative effect of anywhere from 0 to 2 W/m².

Greenhouse gases cause positive forcing (warming), and scientists have a very good understanding of how they effect climate

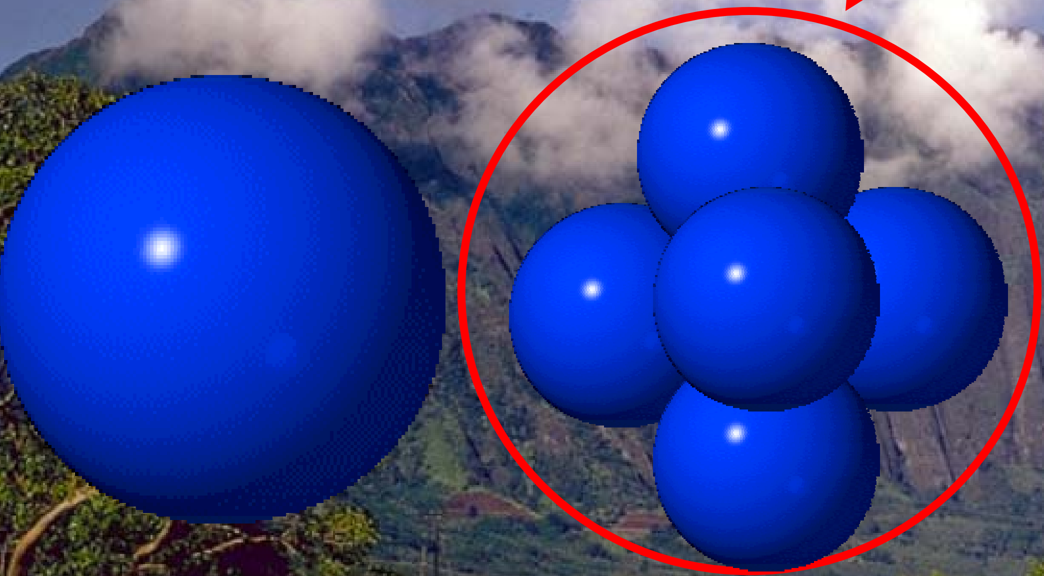
Effect of Aerosols on Climate

- Aerosols are suspended particles in the atmosphere: sulfates, organic carbon, black carbon, sea salt, etc.
- **They can have a <u>direct effect.</u>**
  - **absorption or scattering of solar radiation**
- **Aerosols also have a <u>semi-direct effect.</u>**
  - **Black carbon absorbs solar radiation, thereby warming the atmosphere and cooling the surface. This stabilizes the atmosphere, suppressing clouds and convection. The variation in cloud cover and convection then affects the radiation budget.**
- **The most complex effect of aerosols is the <u>Aerosol Indirect Effect (AIE)</u>**

- Clouds form when water vapor condenses onto small particles in the air called condensation nuclei.
- Aerosols can act as condensation nuclei, thereby increasing the number of cloud droplets in a cloud.
- Given an equal amount of water in a cloud, if there are more droplets then each droplet must have less water (smaller size).



- A cloud with a greater number of small droplets has more reflective surface area than a cloud of the same volume with fewer large droplets.
- Therefore, aerosols increase the reflective surface area of the cloud by acting as condensation nuclei.
- This is the **first indirect effect**, or Twomey Effect.



- Clouds precipitate when droplets collide and coalesce.
- If droplet size is smaller because of increased aerosols, then the clouds will not precipitate as much.
- If the cloud does not precipitate, then it retains its water, lasts longer, and becomes larger and more reflective.
- This is the **second indirect effect**.

How to study the AIE on a global scale?

- POLDER (POLarization and Directionality of the Earth’s Reflectances)
- developed by France, launched onboard Japanese satellite
- has been used in most satellite studies of AIE up until now

- MODIS (MODerate resolution Imaging Spectroradiometer)
- launched by NASA in 1999 and 2002
- more reliable data released in the past year or so
- very few studies on AIE using MODIS

Purpose

To find evidence for the first and second aerosol indirect effect using data from MODIS, and to identify aerosol - cloud microphysical relationships across the globe.

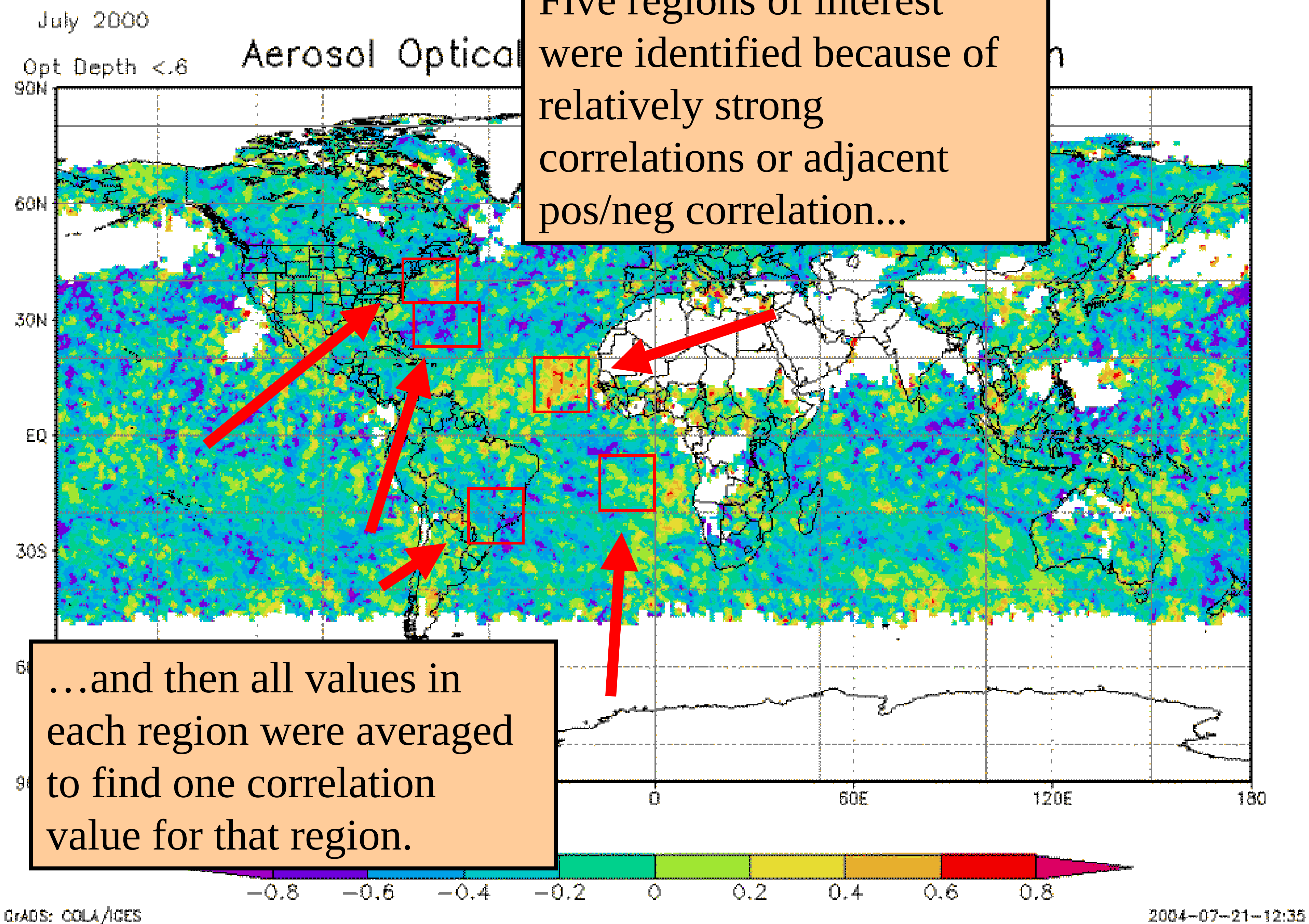
Data

- 9 Variables were obtained from MODIS July 2000 Data
  - Cloud Top Temperature (K) -CTP
  - Cloud Top Pressure (hPa) -CTT
  - Cloud Droplet Number Concentration -NC
  - Total Cloud Fraction
  - Water Path (g/m^2)
  - Cloud Effective Radius (microns) - REFF
  - Cloud Optical Thickness - COT
  - Cloud Condensation Nuclei (CCN/cm^2)
  - Aerosol Optical Thickness -AOT
- July 2000 was chosen for this study because aerosols are more prevalent and aerosol climate models use emission data from 2000 to simulate aerosol effects on present-day climate.
- The data is organized in a 1x1 degree global grid for each day

Methodology - First Correlation Test

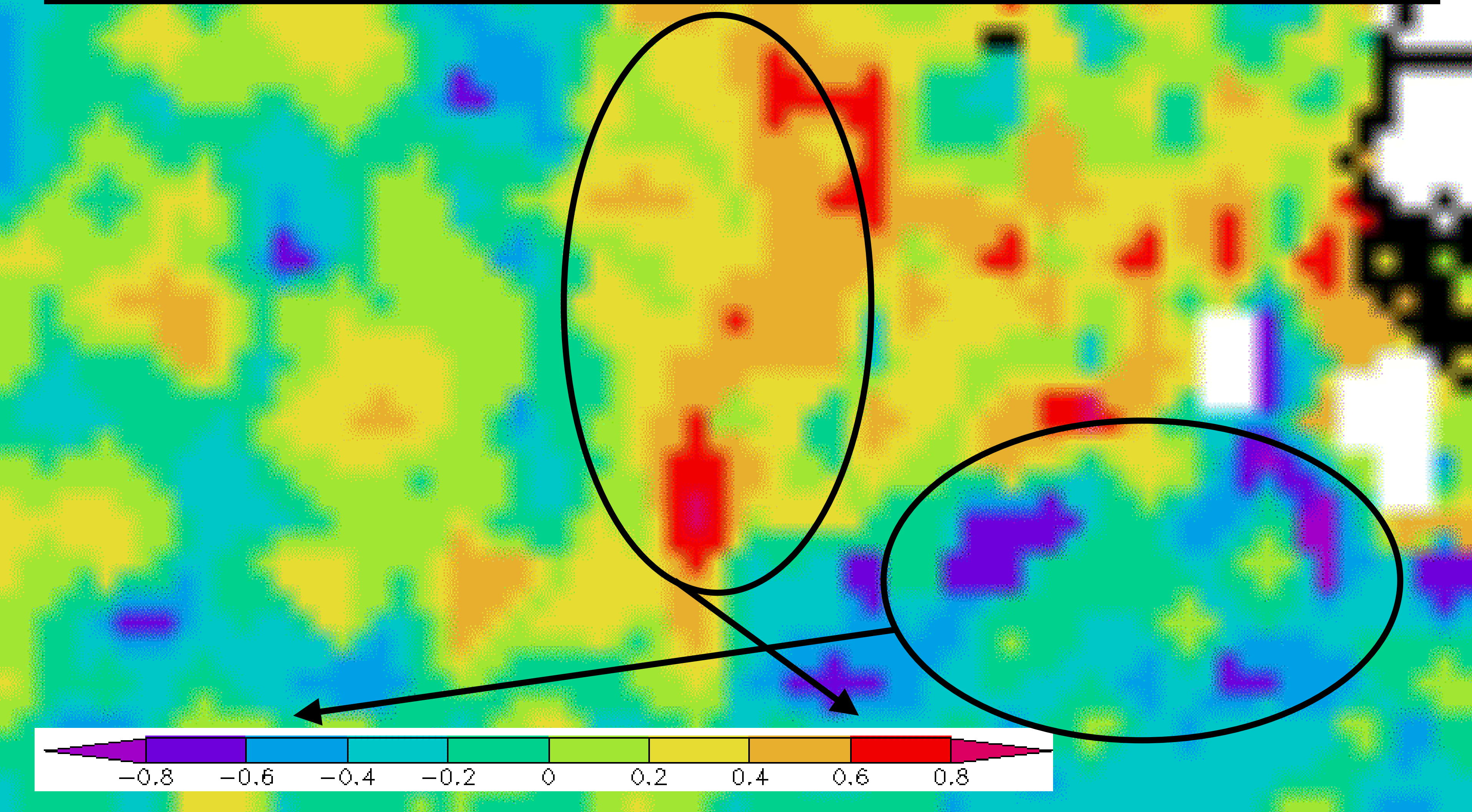
- Aerosol optical thickness and cloud optical thickness were correlated with each of the other variables
- A correlation was found for each 1x1 degree grid point on Earth using the 31 points available for each point (from each of the 31 days in July)
- Some instrument errors were accounted for and data was filtered out
- If there were less than 5 valid points left for a grid point, then the correlation was marked as missing for that grid point
- The data was visualized on a global map...

Five regions of interest were identified because of relatively strong correlations or adjacent pos/neg correlation...

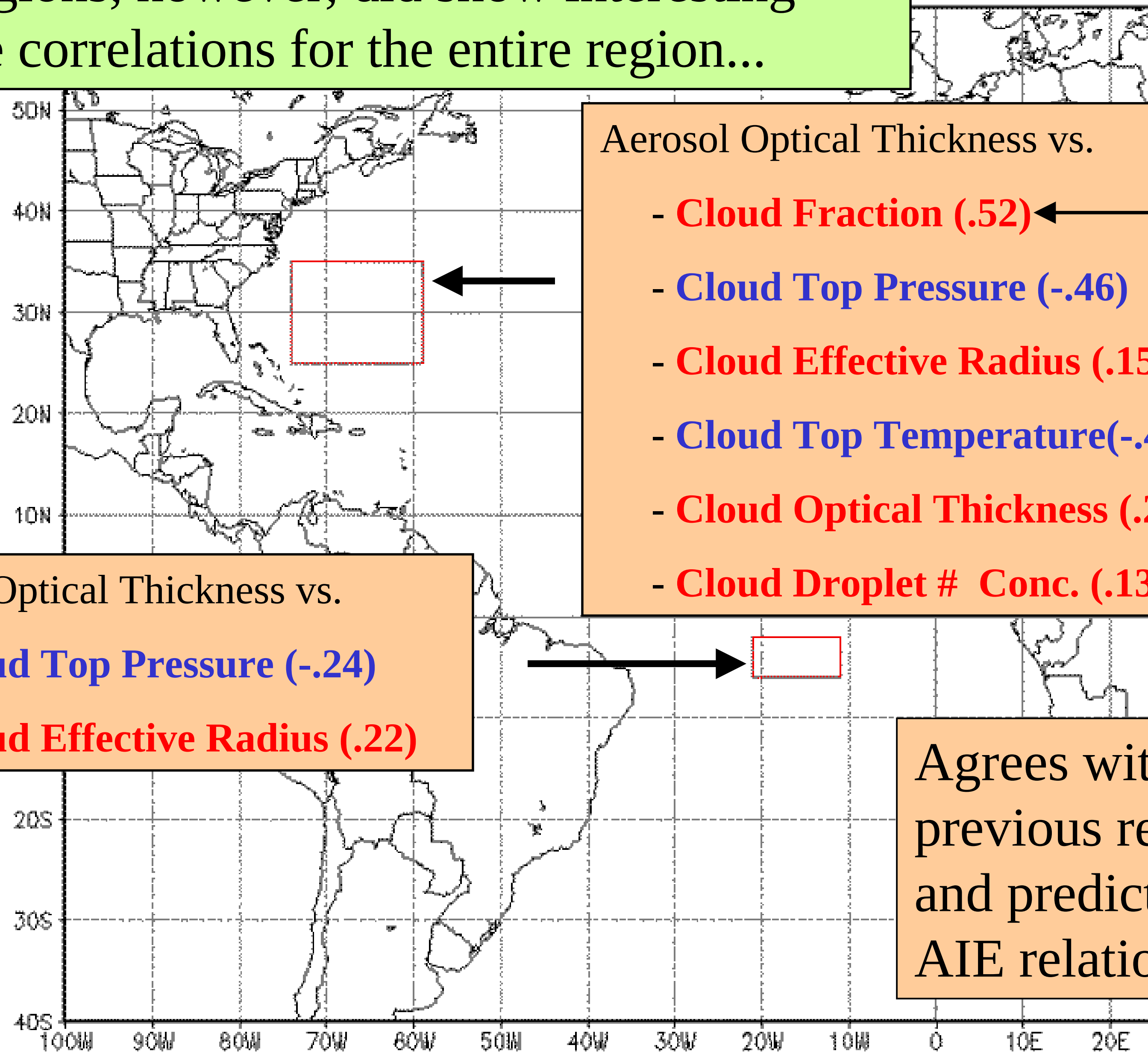


…and then all values in each region were averaged to find one correlation value for that region.

When you zoom in on the regions, you notice that the areas of positive correlation are interspersed with regions of negative correlation. This leads to very weak average correlations and statistically insignificant results in most regions.



Two regions, however, did show interesting average correlations for the entire region...



Aerosol Optical Thickness vs.

- **Cloud Fraction (.52)**
- **Cloud Top Pressure (-.46)**
- **Cloud Effective Radius (.15)**
- **Cloud Top Temperature(-.41)**
- **Cloud Optical Thickness (.24)**
- **Cloud Droplet # Conc. (.13)**

Aerosol Optical Thickness vs.

- **Cloud Top Pressure (-.24)**
- **Cloud Effective Radius (.22)**

Agrees with previous research and predicted AIE relationships

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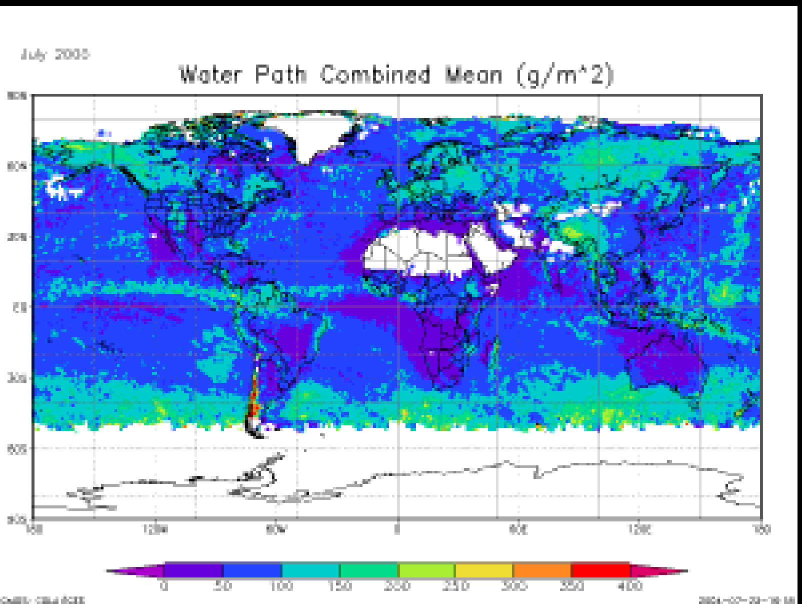
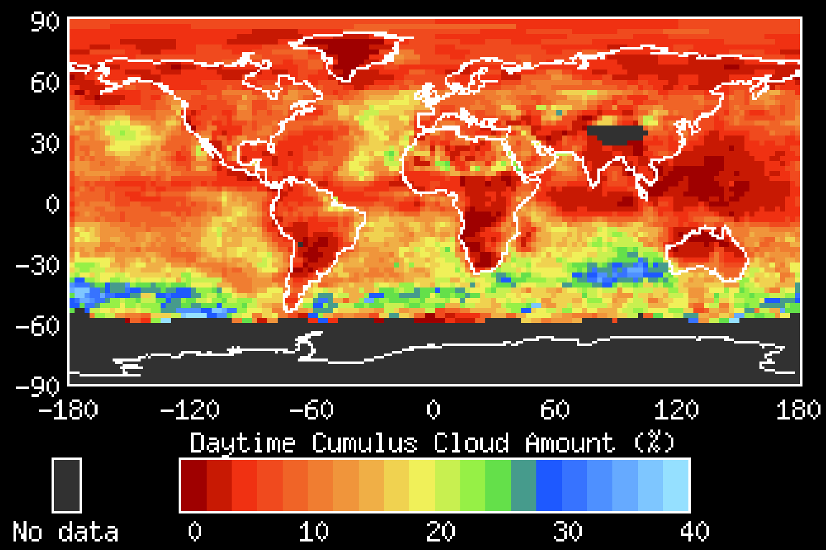
Methodology - Second Correlation Test

- We selected 20 regions around the globe based on:
  - dominant stratus or convective clouds determined by ISCCP data (International Satellite Cloud Climatology Project)
  - consistent cloud top pressure determined by MODIS
  - consistent cloud top temperature determined by MODIS
  - consistent water path determined by MODIS
- Important so variation caused by water content, temperature, and pressure could be ignored and we could focus just on cloud properties related to the AIE



ISCCP-D2 Monthly Mean for July 2000



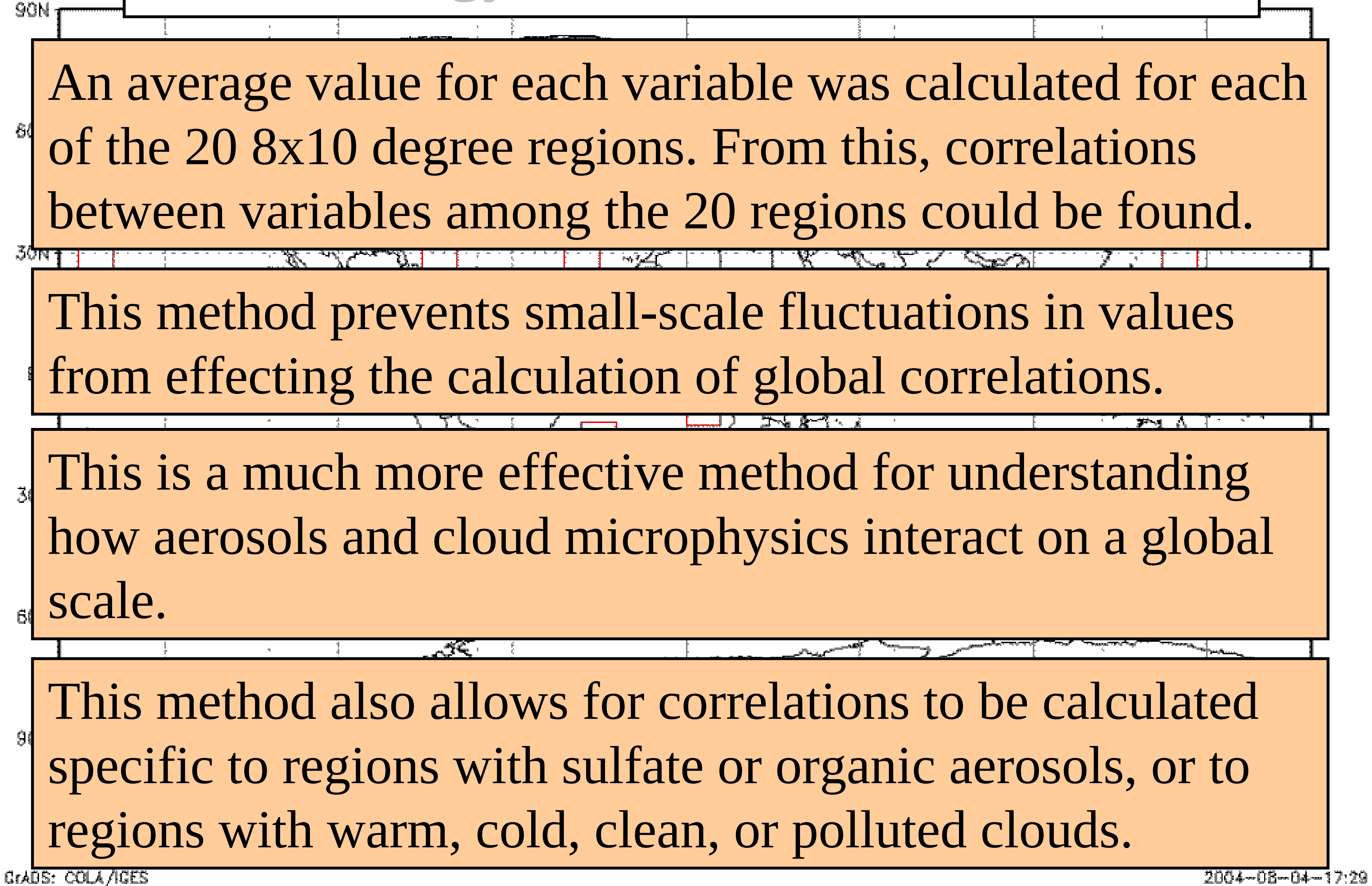
Methodology - Second Correlation Test

An average value for each variable was calculated for each of the 20 8x10 degree regions. From this, correlations between variables among the 20 regions could be found.

This method prevents small-scale fluctuations in values from effecting the calculation of global correlations.

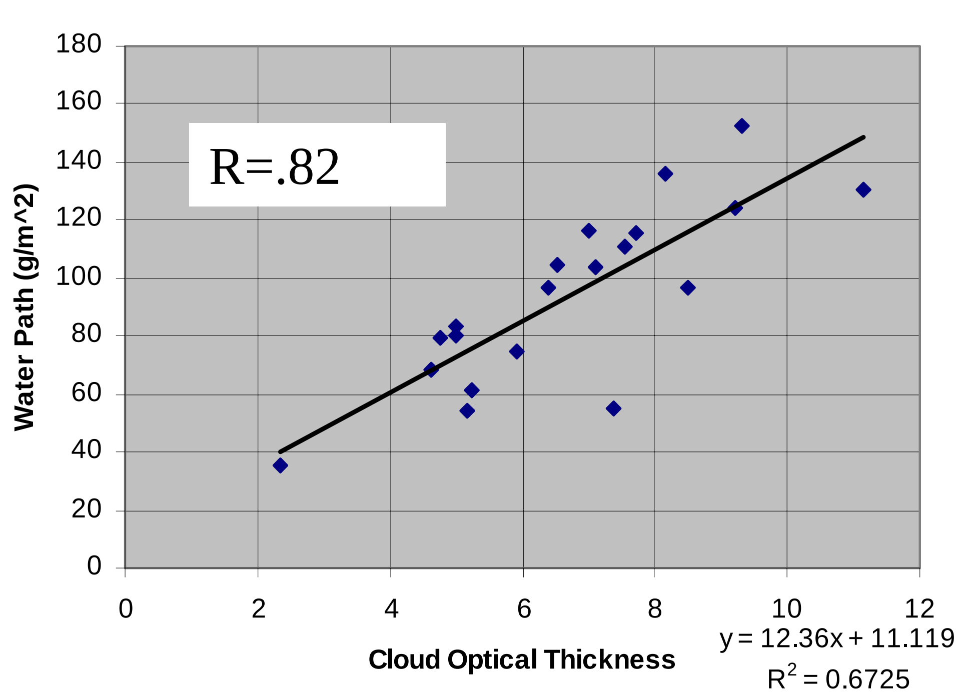
This is a much more effective method for understanding how aerosols and cloud microphysics interact on a global scale.

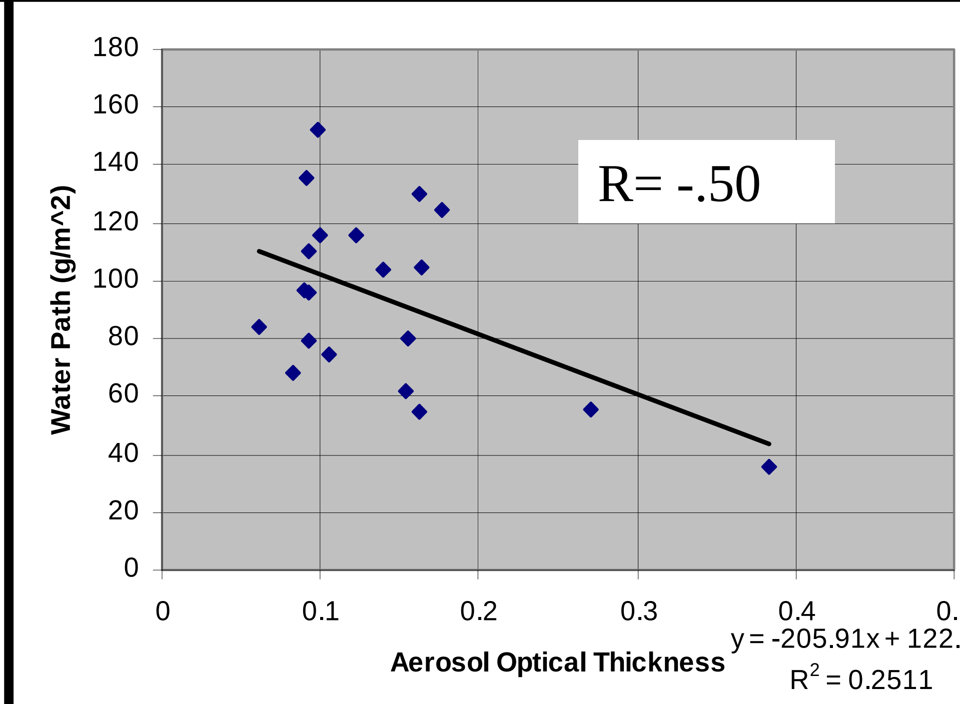
This method also allows for correlations to be calculated specific to regions with sulfate or organic aerosols, or to regions with warm, cold, clean, or polluted clouds.



Results - Second Correlation Test

- Of most significance is the large variability in the water path (water content of each column)
- Strong correlations between water path and cloud optical thickness, aerosol optical thickness, and effective radius
- Indicates that reflectivity of each cloud (cloud optical thickness) is greatly affected by the water path





Results - Second Correlation Test

- The data was separated into three subsets with similar water paths
- The first subset contains 5 regions where water path averaged between 110 and 130 g/m²

	AOT	TEMP	CTP	NC	FRACT	COT	REFF	Wtr Pth	CCN	Clouds
3	0.0927	282.6	810.2	809922	0.7303	7.536	20.84	110.47	0.017	C
5	0.1218	260.8	552.8	402719	0.6132	7.73	27.58	115.83	0.019	D
8	0.1773	266.1	624.6	720866	0.5658	9.2	24.76	124.21	0.044	C
13	0.1001	271.6	700.1	351559	0.519	7.018	26.72	116.15	0.012	C
18	0.162	269.1	689.8	1.74E+06	0.8169	11.14	16.89	130.11	0.046	S

Very low Effective Radius values, very high cloud droplet # concentration values

Very high Effective Radius values, very low cloud droplet # concentration values

1st

A

I

E

Low Effective Radius values, high cloud fraction and implied thickness (reflectivity)

Very high effective radius values, low cloud fraction and implied thickness

2nd

A

I

E

Results - Second Correlation Test

- The second subset contained 6 regions with water path values between 60 and 80 g/m^2, and the third subset contained just two regions with nearly identical water paths ~55 g/m^2.
- All regions showed the same INVERSE relationship between the size of the water droplet (effective radius) and column cloud droplet number concentration
- All regions also showed the same INVERSE relationship between size of the water droplet and both cloud optical thickness (reflectivity) and cloud fraction.

Increased Aerosols

Direct relationship

# of Cloud Droplets,
Cloud Fraction,
Cloud Optical Thickness

Inverse relationship

Droplet Radius

Results - Second Correlation Test

- The data was also constrained by aerosol optical thickness (clean <.1 vs. polluted clouds >.1)
- If the AIE is occurring, there should be a strong positive correlation between aerosol optical thickness and water path
  - More Pollution >> More Condensation Nuclei >> Smaller Droplet Size >> Less Precipitation >> More Water in Cloud
- **A strong positive correlation, however, only showed up in clean clouds (.51)**
- In polluted clouds, there was actually a **stronger negative correlation between aerosols and water path (-.61)**
  - contradicting expected AIE

Results - Second Correlation Test

- Another interesting result appeared when cold clouds (cloud top temp. <273) were separated from warm clouds (cloud top temp >273).
- **In warm clouds, a strong negative correlation appears between aerosol optical thickness and cloud top pressure (-.70) and cloud top temperature (-.40)**
- **In cold clouds, a strong positive correlation appears between aerosol optical thickness and cloud top pressure (.52) and cloud top temperature (.55).**

Conclusions

- Water path, which is effectively the water content of a column, greatly affects cloud properties (droplet radius and concentration, optical thickness, fraction, top temperature and pressure, etc.)
- Water path also appears to be correlated with the aerosol optical thickness -- more polluted warm clouds appear to have lower water paths
- To discern the influence of aerosols on cloud properties, the water path needs to be constrained
- Once that is done, MODIS data does provide evidence for the first and second aerosol indirect effect
  - Cloud droplet size decreased with more pollution in both warm and cold clouds
  - However, corresponding changes in cloud optical properties were more difficult to obtain
  - Evidence for the second aerosol indirect effect is mostly obtained for clean clouds (aerosol optical thickness <.1)

Future Work

- Identify specific dynamic regimes using reanalysis data and look for similar statistical relationships between aerosols and cloud microphysics under these regimes
- Identify if prevailing winds over regions originate from landmasses, oceans, or areas of known biomass burning
- Use global dispersion model to identify the type of aerosols present in each region and investigate if that might explain the different relationships seen in the data

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